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(71) Applicant: AGFA-GEVAERT
naamloze vennootschap
B-2640 Mortsel (BE)

(72) Inventors:
- Delabastita, Paul,
c/o Agfa-Gevaert N.V.,
B-2640 Mortsel (BE)
- Daels, Katrien,
c/o Agfa-Gevaert N.V.,
B-2640 Mortsel, (BE)
- Van Hunsel, Johan,
c/o Agfa-Gevaert N.V.,
B-2640 Mortsel, (BE)
- Van Cauwenberge, Jan,
c/o Agfa-Gevaert N.V.,
B-2640 Mortsel (BE)

(54) Improved halftone screen and method for making same

(57) In order to improve the printability of a periodic halftone screen, the amount of growth of the halftone dots in a halftone screen is modulated as a function of tone in a tone selective way that is different for at least two halftone dots. In one embodiment for low densities the number of dots of substantially equal area is modulated, and for high densities the area of dots is modulated.

0	1	103	62	42	101	141	131	49	79	99	40
2	50	143	133	83	81	121	91	36	37	59	60
94	70	123	113	20	21	45	69	38	39	134	124
84	24	27	73	23	22	55	138	108	78	104	114
46	25	26	137	107	65	98	128	118	12	15	74
110	66	56	127	117	87	7	88	92	13	14	53
140	130	48	77	97	41	4	5	102	63	43	100
120	90	32	33	58	61	6	51	142	132	82	80
47	68	34	35	135	125	95	71	122	112	28	29
57	136	106	76	105	115	85	16	19	72	31	30
96	126	116	8	11	75	44	17	18	139	109	67
3	86	93	9	10	52	111	64	54	129	119	89

Fig. 6

Table I

lpi	100	110	120	133	150	175	200	250	300	350	400	500
1%	29	26	24	22	19	16	14	11	10	8	7	6
2%	41	37	34	30	27	23	20	16	14	12	10	8
3%	50	45	41	37	33	28	25	20	17	14	12	10
4%	57	52	48	43	38	33	29	23	19	16	14	11
5%	64	58	53	48	43	37	32	26	21	18	16	13
6%	70	64	59	53	47	40	35	28	23	20	18	14
7%	76	69	63	57	51	43	38	30	25	22	19	15
8%	81	74	68	61	54	46	41	32	27	23	20	16
9%	86	78	72	65	57	49	43	34	29	25	21	17
10%	91	82	76	68	60	52	45	36	30	26	23	18
11%	95	86	79	71	63	54	48	38	32	27	24	19
12%	99	90	83	75	66	57	50	40	33	28	25	20
13%	103	94	86	78	69	59	52	41	34	30	26	21
14%	107	97	89	81	71	61	54	43	36	31	27	21
15%	111	101	93	83	74	63	56	44	37	32	28	22
16%	115	104	96	86	76	66	57	46	38	33	29	23
17%	118	107	98	89	79	68	59	47	39	34	30	24
18%	122	111	101	91	81	69	61	49	41	35	30	24
19%	125	114	104	94	83	71	62	50	42	36	31	25
20%	128	117	107	96	85	73	64	51	43	37	32	26
21%	131	119	109	99	88	75	66	53	44	38	33	26
22%	134	122	112	101	90	77	67	54	45	38	34	27
23%	137	125	115	103	92	79	69	55	46	39	34	27
24%	140	128	117	106	94	80	70	56	47	40	35	28
25%	143	130	119	108	96	82	72	57	48	41	36	29

There is hence a trade off to be made in flexography between the requirements on the range of tones that can be consistently reproduced and the spatial resolution of the image.

Despite its higher resolution, the offset printing process exhibits the same fundamental problem : depending on the quality of the paper and the specifics of the printing process, the maximum frequency of the halftone screen, and hence the spatial resolution, is limited by the demand of a consistent halftone dot reproduction across the tone scale. Few offset processes are capable to render images with halftone frequencies higher than 200 lpi without jeopardizing the smoothness of the highlight tone rendition

A similar situation occurs in electrophotographic printing : a minimum dot size is necessary in order to obtain stable rendering of the halftone dots

A solution has been proposed for the above problems by using frequency modulation (FM) halftoning techniques. The tone modulation in these techniques is obtained by varying the average-distance between fixed sized halftone dots. By selecting a size for the halftone dot that is large enough for consistent reproduction, the above problems are avoided. FM screening however, has its own drawbacks. Especially in the midtones, the fixed sized halftone dots exhibit a larger total circumference than the halftone dots in a periodic screen and are therefore more sensitive to variations in size during the various stages of the reproduction process. In addition are most FM screens prone to "graininess", which is par-

to have regions with different optical densities. These optical densities may be measured by a densitometer or color densitometer. The optical densities meant here are spatially integrated optical densities, as opposed to micro densities. A densitometer suited for measuring this type of densities typically illuminates a region larger than one millimetre by one millimetre, and measures the intensity of the reflected or transmitted light, in order to generate a density value for the illuminated region. A region with low optical density is a region, comprising at least five grid points, which has an almost constant integrated optical density. The feature that the number of halftone dots is in accordance with said low density, means that the number of halftone dots within regions having the same area but a different corresponding density, may be different and will be different if the density difference is large. In a preferred embodiment, the relation between the density and the number of halftone dots of a specific region is never decreasing. This means that the number of halftone dots preferentially does not decrease if the density increases. Preferentially, as a function of increasing density within a low density region, the area of the smallest halftone dot(s) within that region increases, and once a fixed dot area is reached, a new halftone dot is started on a grid point, having now the smallest area. This variation in number of halftone dots is necessary to compensate for the area of most of the halftone dots, which is preferentially fixed within low density regions. This fixed dot area is preferentially selected such that these halftone dots can be consistently reproduced. The majority of halftone dots must have an area substantially equal to a fixed dot area. By a majority is meant 66% or more. A low density region, according to the current invention, containing nine halftone dots, may have at most three smaller sized halftone dots. The requirement that this majority has an area substantially equal to the fixed dot area means that these halftone dots may have slightly varying dot areas, e.g. with a variation of 25%, or, where in electronic screening the halftone dots are built up of several microdots, a variation of one microdot more or less than a fixed dot area, which may be equivalent to the number of microdots within the halftone dot. By these technical features, the advantageous effect is achieved that the tone rendering of reproductions is more predictable as from the start of the printing process and the endurance of a printing plate is substantially increased, without loss of quality in the output image.

In a more preferred embodiment, substantially every grid point, within a region corresponding with a high density, is occupied by one halftone dot. This means that 90% or more of the grid points corresponding to an autotypical raster are occupied by a halftone dot in such high density region. In a region according to the higher density, an amplitude modulation screening technique is thus preferentially used. Moreover, preferentially the area of substantially each halftone dot within such a region, is not smaller than the fixed dot area as discussed above. This means that 90% or more of the halftone dots in such a region corresponding with a high density have an area equal to or larger than the fixed dot area, which is preferentially the dot area which may be reproduced consistently.

The advantageous effects may also be obtained by a photomechanical screen that is devised such that it generates the required halftone dots. In the photomechanical production of a screened image, a photosensitive medium is illuminated by the image to be reproduced, through a photomechanical screen. Usually, the density distribution on such a photomechanical screen is with regular "mountains" and "valleys". If the density distribution is chosen such that the screen comprises a plurality of spotlike zones, arranged on grid points of a periodic grid, defined by a screen angle and a screen ruling, and wherein each spotlike zone has a plurality of different optical densities within a narrow density range, wherein that density range is disjunctive from the density range of at least two closest other spotlike zones, then the effect will be that, if a continuous tone image is screened by such a screen, the majority of the halftone dots will preferentially have an area not smaller than a minimum area Because there is an analogy between a photomechanical screen and a threshold matrix, i.e. that a photomechanical screen may be seen as a continuous tone image generated by converting the threshold values in density levels on a support or that a threshold matrix may be seen as the electronically scanned output of a photomechanical screen, a photomechanical screen and a threshold matrix are equivalent. Optical densities on a photomechanical screen are equivalent to threshold values, and a density range is equivalent to a range of threshold values. Preferentially, these spotlike zones are surrounded by zones having an optical density that is more distributed over the different spotlike zones. The combination of a screen with a continuous tone image may happen as described above in a photomechanical process. This combination may be done electronically, in an apparatus as described in conjunction with Fig. 8 below.

A continuous tone image belongs to that class of imagery, containing multiple grey levels with no perceptible quantisation to them. Halftone pictorial is composed ideally of only two grey levels, e.g. black and white. Grey, black and white may be substituted by any other process color in color printing. In the method according to the current invention, also multilevel halftoned images may be produced, by which is meant that this pictorial is composed of more than two grey levels, but that usually different grey levels have a perceptible quantisation.

A threshold matrix is said to be suitable for periodically tiling a plane, meaning that the threshold matrix may be repeated horizontally and vertically, or in any other direction, such that adjacent threshold matrices fit to each other. A threshold matrix may be square or rectangular, but may also have a diamond shape, an L shape or whatever shape, which is suitable to tile a plane. Specific threshold matrices and tiling methods may be found in US 5,155,599 and EP 0 427 380 A2.

A halftone dot environment is a region around a halftone dot center, which may have any shape : circular, elliptical, square, rectangular, etc. An important restriction which is put on such a halftone dot environment is that is contains no

If this distance would be the same for two or more "candidate halftone dots", the third ordering number is given to that candidate halftone dot, that maximizes the average distance between all three halftone dots.

The same procedure is preferentially used to select the fourth, fifth,... halftone dot, until all the halftone dots in the tile have received an ordering number.

It can be shown that the above algorithm leads to halftone dot distributions that have desirable "blue noise" characteristics.

The above algorithm was used to assign a sequence number, ranging from 0 to 9, to the 10 halftone dots (22) in the supercell (21) of Fig. 3.

Step 2 : assignment of first set microdots to halftone dots

This is preferentially done by means of three nested loops.

Before the outer loop is started, a variable, indicated by "relcounter", is initialized to 0. The outer loop controls the order according to which every halftone dot is "visited".

Before the middle loop is started, a variable, indicated by "sizecounter", is initialized to 1. The middle loop keeps track of the size of the halftone dot that is "being visited".

In the inner loop, a spotfunction, identified by "S(dot,rel)", is evaluated for each microdot, belonging to the tile, which has not been assigned yet to a halftone dot. An example of such a spotfunction is :

$$S(dot,rel) = (X_{dot} - X_{rel})^2 + (Y_{dot} - Y_{rel})^2$$

- (X_{dot},Y_{dot}) represents the position coordinates of the center of the halftone dot or shortly "halftone dot center" ;
- (X_{rel},Y_{rel}) represents the position coordinates of a candidate microdot, also referred to as "microdot center" or, in conjunction with a threshold matrix : "center of threshold matrix element" ;
- the spotfunction itself S(dot,rel) corresponds to the square of the Euclidean distance between the halftone dot center (X_{dot},Y_{dot}) and the position of candidate microdot (X_{rel},Y_{rel}).

At the end of the inner loop, that one microdot is retained, that yields the lowest value for the spotfunction, and the value of the variable "relcounter" is assigned to it, after which the variables "relcounter" and "sizecounter" are incremented by one.

The microdot that has received the value is now being marked as "assigned" to a halftone dot.

By adding a small random value to the position coordinates (X_{dot},Y_{dot}) of the halftone dot center, the possibility that two candidate microdots would yield the same spotfunction value can be virtually eliminated.

If the incremented value of the variable "sizecounter" exceeds a certain preset value "maxsizecounter", the algorithm proceeds by returning to the beginning of the outer loop, at which point the next halftone dot is "visited". Otherwise does it proceed by returning to the beginning of the middle loop, at which point the search for a next microdot for the same halftone dot or within the halftone dot environment is started.

When the outer loop is left, the following equation holds :

relcounter = number_of_dots * maxsizecounter + 1

```
do until (relcounter = number_of_rels) {
        for (all the halftone dots in the supercell,
             in order of their assigned sequence)     {
                for (all microdots in supercell that have not been
                    assigned yet to a halftone dot)  {
                        evaluate spotfunction of microdot in
                        combination with halftone dot.
                }
                assign the value relcounter to the microdot
                that yields the lowest spotfunction value
                relcounter=relcounter+1
        }
}
```

The above algorithm was used to give the other values required in the matrices according to Fig. 5 and Fig. 6.

For large supercells, it is desirable to optimize the speed of the algorithm. This is preferentially done by limiting the search, in the inner loops of the second and third step, for the microdot yielding the lowest spotfunction value, to the microdots that are adjacent to the microdots that were previously assigned to the same halftone dot that is being visited. Another speed improvement may be realised by precalculating and storing in a look up table all the spotfunction values of all the microdots in combination with all the halftone dots. The evaluation of the spotfunction in that case is replaced by a table look up, which is significantly faster than the evaluation itself, especially when a spotfunction is used that involves heavy floating point arithmetic.

Step 4 : rescaling the range of matrix elements

At the end of step 3, a square matrix with TS*TS elements is obtained. According to the above algorithm, such a matrix contains values ranging from 0 to number_of_rels-1. Before this matrix is used as a screening threshold matrix, its elements are preferentially rescaled to match the range of input image pixels to be screened electronically. For a system with 8 bits, the range of the input image pixels is from 0 to 255. Therefore the range of threshold values is preferentially expanded to the range [1,255]. This may be done by :

- multiplying every element by a constant factor equal to 254/143 ;
- adding 1 to the result ; and,
- rounding the result to the closest integer number.

This leads to the matrix shown in Fig. 7. As can be seen, this threshold matrix represents a screen (photomechanical or electronic threshold matrix), suited for the transformation of a continuous tone image into a halftone image (as will be discussed in conjunction with Fig. 8), wherein said screen comprises a plurality of discrete spotlike zones (each showing four bold adjacent threshold values in Fig. 7 ; for the values 1,3,5,6 the threshold matrix must be tiled as in Fig. 4), arranged on grid points of a periodic grid (compare Fig. 7 with Fig. 3), defined by a screen angle (α) and a screen ruling (1/A), each spotlike zone having a plurality of different optical densities (e.g. threshold values 1,3,5,6 ; 8,10,12,13 etc., which are equivalent to optical densities of a photomechanical screen) within a narrow density range (e.g. [1,6] ; [8,13] etc.), said density range being disjunctive with a density range of at least two closest other spotlike zones. A spotlike zone closest to 8,10,12,13 is 22,24,26,28 and $[8,13] \cap [22,28] = \varnothing$. In a more preferred embodiment, any region around such a spotlike zone (non-bold threshold values in Fig. 7) has a plurality of optical densities (or threshold values) within a wide density range, said density range having a large overlapping portion with any density range of such other regions. E.g. the region around 37,38,40,42 has threshold values 237, 148, 145, 216, 81, 99, 175, 116, 191, 244, 131, 202, all within a range of [81,237], whereas the region around 58,60,61,63 has threshold values 232, 86, 138, 173, 104, 241, 188, 136, 189, 243, 122, 161, all within [86,243]. The overlapping portion is : $[81,237] \cap [86,243] = [86,237]$, which is a large overlapping portion. The threshold matrix according to Fig. 7 may be used in a device according to Fig. 8 for converting a continuous tone image into a halftone image, by combining the threshold values with the contone pixel val-

EXAMPLE

A comparison was made between a classic autotypical screening technique, called Agfa Balanced Screening (ABS), as described in US 5,155,599 and three versions of a screening technique according to the current invention, using the same screening parameters. The screen ruling was chosen 148 lpi and the screen angle 15°, and the shape of the halftone dots was round. According to the first version (VI), halftone dot percentages of 4% and lower were achieved by reducing the number of halftone dots, rather than their size. This meant that the fixed dot area corresponds with a dot size of 38 μm. According to the second version (V2), the transition dot percentage was chosen 5%, corresponding to a 42 μm halftone dot size. For the third version (V3), the transition dot percentage was chosen 6%. These three versions avoid the appearance of dots smaller than 38 μm, 42 μm or 47 μm, which may not print at all or miss printing endurance.

ABS, V1, V2 and V3 type screened images of a continuous grey wedge and of constant grey patches were recorded on SFP812p film on an image setter SelectSet Avantra 25, working at a recorder pitch of 2400 microdots per inch, with exposure setting of 190. After exposure to the halftone image, the latent image on the film was developed. This film was then used in a Thermer contact frame, to expose a Lithostar LAP-B printing plate precursor. After exposure, the plate was developed in a fresh L5000 developing bath. A second plate, exposed in the same conditions, was developed in the same L5000 bath, which was however conditioned to steady-state use conditions, by developing 5 m^2 plate material per litre of developing bath.

The printing plate thus obtained was printed on a Heidelberg GT052 press with Hartmann S6920 ink and Rotaprint Rotamatic fountain solution (1 part fountain solution additive + 1 part water). The paper used was KNP Royal Impression Brilliant gloss-coated paper 115 g/m². From the prints it was clear that V1, V2 and V3 according to the current invention give better results in areas with small per cent dot area than the print according to the ABS technique. By visual inspection it was established that the smallest per cent dot area that can be reproduced by ABS in optimal development conditions is 3%. V1, V2 and V3 allow reproduction of 0.5 per cent dot area. If the developing agent was not fresh, ABS reproduced consistently only from 3.5% and higher on. This test may thus also be used to establish the fixed dot area, below which the number of halftone dots is varied rather than their size.

A second test was done to assess the improvement of printing endurance. The same exposure and development conditions (steady-state developing bath) of the printing plate were followed as in the test above, but other printing conditions were used. A SAKURAI Oliver 52 press, with BASF K+E 171 ink and a fountain solution comprising 3% Aquaayde and 4% Tame, both from Anchor. Uncoated paper 80 g/m² was used. The printing endurance according to V1 was substantially better than that according to ABS. V2 was even better than V1, V3 was optimal with respect to long term printing endurance in these printing conditions. After printing 100 sheets, ABS points with 2.5% were hardly visible, whereas after 10,000 sheets they disappeared below 3.5% and after 25,000 sheets they disappeared below 4%. According to V1, 0.5% remained visible up to 10,000 sheets. At 25,000 sheets, visibility disappeared below 4%. According to V2, 0.5% remained visible up to 25,000 sheets. According to V3, no quality was lost, i.e. no density was lost in the highlights, up to 25,000 sheets.

The invention can also be applied for rendering devices, capable of reproducing more than two tone values, such as in a xerographic printing process.

The invention can also be used in color printing applications, where a different halftone screen is used for each color separation. A specific example of such a technology is described in US 5,155,599.

The frequency modulation halftoning technique on an autotypical grid may also be successfully applied to "halftone dot holes" within regions corresponding with a high density. Whenever a specific density is reached, e.g. 95% dot point, it is possible that some "holes" tend to fill up. Once a dot percentage is reached that this may cause problems to consistently reproduce images, the area of the holes may be kept constant and the number of holes may be decreased whenever the density must be increased.

Summary of terms (in alphabetical order)

maxsizecounter:	a constant value, indicating the size of the halftone dot, in number of microdots, at which the heuristic algorithm stops assigning subsequent microdots to a single halftone dot, and starts assigning subsequent microdots to different halftone dots
number_of_dots:	total number of halftone dots in a supercell. In a supercell of the type described in Fig. 3, this value is equal to A^2+B^2
number_of_rels:	total number of microdots in a supercell. In a supercell of the type described in Fig. 3, this value is equal to TS*TS
relcounter:	counts the total number of microdots in the supercell, already assigned to any halftone dot, during the heuristic search
sizecounter:	a variable used in the heuristic algorithms to count the number of microdots assigned to one specific halftone dot.
tilesize (TS):	the linear size of a supercell, expressed in number of microdots.

10. Method according to any of claims 7 to 9, wherein :

- substantially on every grid point, within said second region, one halftone dot is generated ; and,
- the area of substantially each halftone dot, generated within said second region, is not smaller than said fixed dot area.

11. Method according to any of claims 7 to 10, wherein the average distance between halftone dots, generated within said first region, is maximized.

12. Method according to any of claims 7 to 11, wherein said low density is lower than a transition density, and said high density is higher than said transition density and wherein said transition density is the density of a region on said reproduction, having on each grid point one halftone dot having said fixed dot area.

13. Method according to any of claims 7 to 12, wherein said fixed dot area is selected such that its density can be consistently reproduced.

14. A screen, suited for the transformation of a continuous tone image into a halftone image, wherein said screen comprises a plurality of discrete spotlike zones, arranged on grid points of a periodic grid, defined by a screen angle and a screen ruling, each spotlike zone having a plurality of different optical densities within a narrow density range, said density range being disjunctive with a density range of at least two closest other spotlike zones.

15. Screen according to claim 14, wherein any region around such a spotlike zone has a plurality of different optical densities within a wide density range, said density range having a large overlapping portion with any density range of such other regions.

16. A method of converting a continuous tone image into a halftone image, comprising the step of combining the intensity of said continuous tone image with the density of a screen according to claim 14 or 15.

17. A screening system comprising a means for converting continuous tone image information to halftone image information is characterised therein that it comprises a means for generating, retrieving or storing a screen according to claim 14 or 15.

18. A method for reproducing a contone image as a halftone image on a recording medium, using threshold values in threshold matrix elements arranged in a threshold matrix, suitable for periodically tiling a plane, comprising the following steps :

- establishing within said threshold matrix a plurality of locations for halftone dot centers, arranged on a periodic grid having a screen angle and screen ruling, each of said halftone dot centers having a halftone dot environment, enclosing just one halftone dot center and comprising a plurality of centers of threshold matrix elements ;
- splitting up the threshold values in a first range and a second range ;
- assigning at least two consecutive threshold values belonging to the first range to threshold matrix elements whose centers are both comprised within one and the same halftone dot environment ; and,
- using said threshold matrix in combination with said contone image to generate a screened image on said recording medium.

19. Method according to claim 18, further comprising the step of assigning each two consecutive threshold values, belonging to the second range, to threshold matrix elements whose centers are comprised in two different halftone dot environments.

20. Method according to any of claims 18 or 19, further comprising the step of imposing an ordering sequence on said halftone dot centers for assigning consecutive threshold values.

21. Method according to any of claims 18 to 20, further comprising the step of rescaling the range of said threshold values according to a range of pixel values within said contone image.

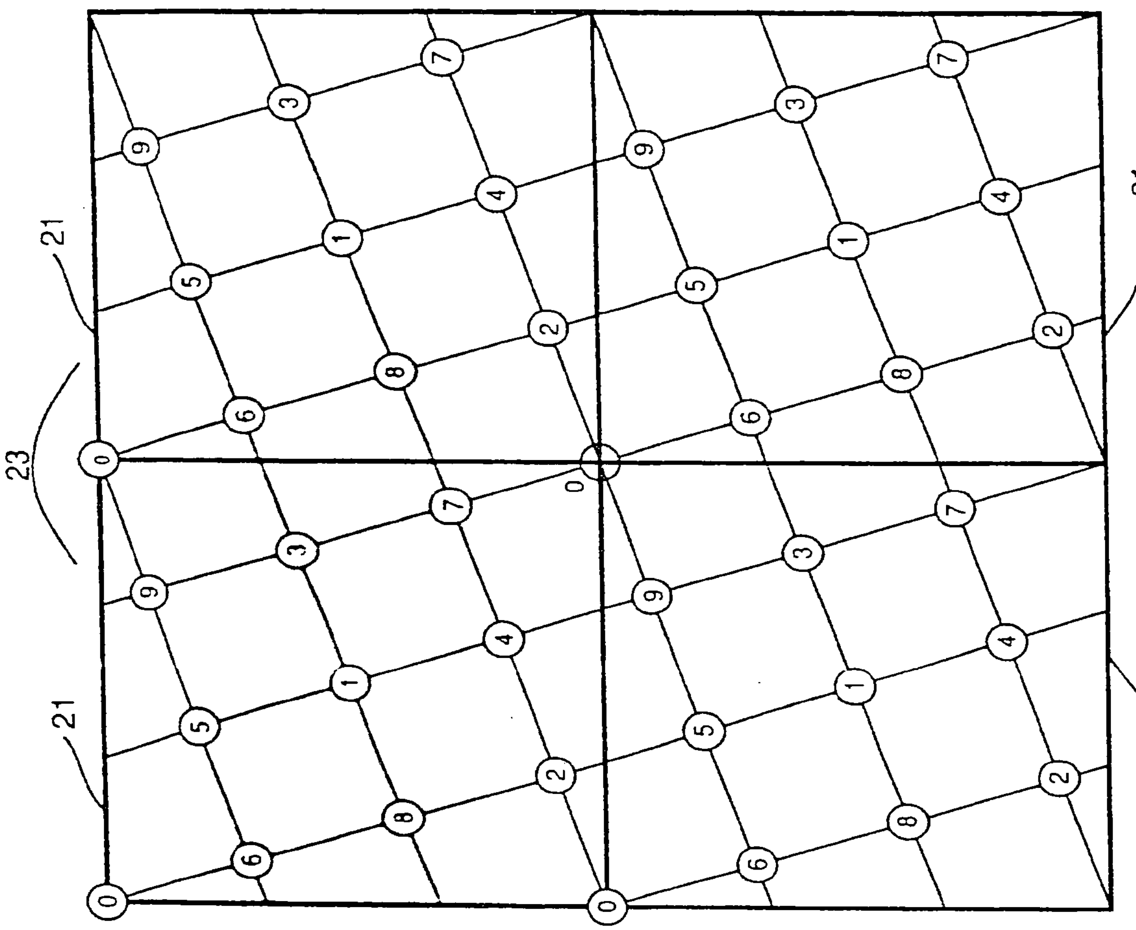

Fig. 4

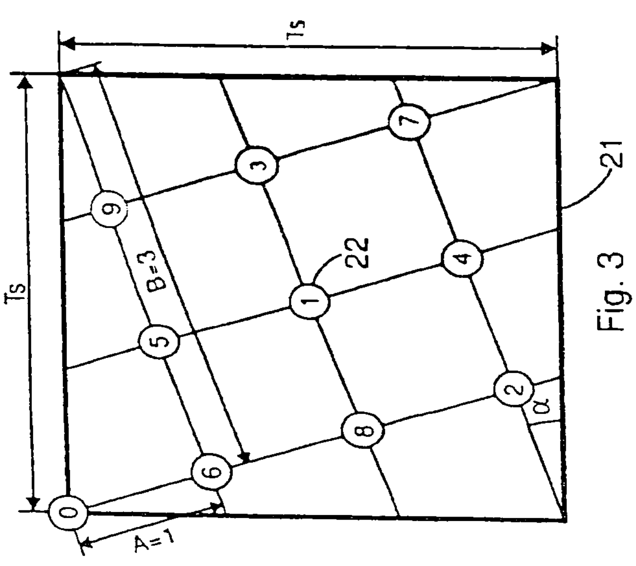

Fig. 3

1	3	184	111	76	180	251	234	88	141	177	72
5	90	255	237	148	145	216	163	65	67	106	108
168	125	219	202	37	38	81	124	68	70	239	221
150	44	49	131	42	40	99	246	193	140	186	203
83	45	47	244	191	116	175	228	211	22	28	132
196	118	100	227	209	156	13	157	164	24	26	95
250	232	86	138	173	74	8	10	182	113	77	179
214	161	58	60	104	109	12	92	253	235	147	143
84	122	61	63	241	223	170	127	218	200	51	53
102	243	189	136	188	205	152	29	35	129	56	54
172	225	207	15	21	134	79	31	33	248	195	120
6	154	166	17	19	93	198	115	97	230	212	159

Fig. 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 20 1096

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y A	US-A-3 197 558 (M. H. M. ERNST) * column 6, line 30 - column 8, line 2 *	1,3,6,7,10,13 2,4,8,9,11 15,18,19	H04N1/405
D,Y	US-A-5 068 165 (P. J. COPPENS ET AL.) * abstract *	2	
Y A	RCA REVIEW, vol.31, no.3, September 1970, PRINCETON (US) pages 517 - 533 R. J. KLENSCH ET AL. 'Electronically Generated Halftone Pictures' * page 522, last paragraph *	4,11 15,18	
D,Y	US-A-4 501 811 (M. SAIKAWA ET AL.) * abstract *	8,9	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
X A	US-A-4 736 254 (H. KOTERA ET AL.) * column 4, line 59 - column 6, line 10 *	14,16,17 15,18,19	H04N
A	US-A-4 752 822 (N. KAWAMURA) * figures 18,21,24,25 *	14-18,20	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17 January 1996	De Roeck, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

European Patent Office

EP 95 20 1096 -B-

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims 1-13,18-21: Rendering optical densities of an image by means of halftone dots: the number of dots of substantially equal area is in accordance with a low density and the area of dots is in accordance with a high density

2. Claims 14-17 : Rendering optical densities of an image by means of halftone dots: close spotlike dot zones have different density ranges